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THE THERMAL CONDUCTIVITY OF LAC AND LAC MOULDING-COMPOSITIONS

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ABSTRACT. The thermal conductivity of lac and lac moulding compositions has been determined at different temperatures by the double-disc method of Lees as modified by the National Physical Laboratory. It has been observed that for certain materials 'aqua-dag' may conveniently be used instead of mercury on the plane faces of heater and cold bars, the advantage being that the former does not interfere with any soldering in the heater or cold bars whereas the latter does. The thermal conductivity of lac moulding compositions is generally of the same order of magnitude as that of phenol-formaldehyde compositions. Water immersion for 24 hours has very little effect on the thermal conductivity of lac, shellac-urea-formaldehyde and shellac-melamine formaldehyde resins, but it affects most of the shellac moulding compositions to an extent dependent upon the nature of the filler. The variation of incumbent pressure on the shellac moulded specimens has no effect on the conductivity.

INTRODUCTION

A knowledge of the thermal conductivity of electrical insulating materials is of utmost importance since the power rating and the behaviour of electrical machineries depend largely on the temperature rise of these materials and the rise of temperature is dependent upon the rate at which heat generated in the electrical and magnetic circuits can be conducted away or dissipated by the cooling medium through these insulating materials. Unfortunately, however, these electrical insulating materials are poor conductors of heat and often a large difference of temperature is necessary between the inner and outer sides of these dielectrics before heat generated in the machineries can pass into the cooling medium outside. The rating of such machineries can therefore be increased by employing dielectrics of greater thermal conductivity or such as can stand a higher temperature rise without their insulating properties being affected. A study of the thermal conductivity of electrical insulating materials is therefore of considerable practical importance.

For a long time shellac has been known to the electrical industry as an insulating material of quality and a considerable percentage of the world's output is consumed annually by this industry in various forms.

The thermal conductivity of lac was measured by Lee[1] as early as 1892 employing the classical method of Lodge[2] and later in 1898 he again repeated

the work by a modification[3] of the method used by him previously. A summary of the previous work relating to this property of lac has been given by Verman.[4] The purpose of the present investigation was to determine the heat conductivity of lac, modified lac and various lac moulding compositions which have been evolved at this Institute and are being used now by some moulding and electrical industries in this country and elsewhere. The object was also to study the effect of temperature and the influence of water on the heat conductivity of these materials, as water and water-vapour have been found to play an important role in the behaviour of lac and some other natural resins regarding some of their physico-chemical properties.

THEORY OF THE METHOD

It is known[5] that when a thin flat disc type electrical heater is enclosed on both sides by two similar discs of a material, the amount of heat generated in the heater flows equally through its two faces when a steady state is reached, if we neglect the very small amount of heat lost radially. The conductivity of the material in such a case is given by

$$k = \frac{Q.l}{2A(\theta_1 - \theta_2)}$$

where k = the conductivity in c.g.s. units,
if Q = the amount of heat in calories supplied per second,
l = the thickness of the material in cms.,
A = the area of one of the discs of the material in sq. cms.,
and θ_1, θ_2 = the temperatures in degrees centrigrade on the two faces of the material.

The amount of heat, Q, generated in the heater may be ascertained from the electrical input energy and the temperatures, θ_1 and θ_2, may be determined by thermo-couples. Hence from the known dimensions of the test-sample of the material, its conductivity, k, may be calculated.

In electrical engineering practice it is sometimes convenient to express heat transference with reference to thermal resistivity instead of thermal conductivity. In such a case, the resistivity

$$K = \frac{0.24}{k},$$

where K is expressed in degrees centigrade to cause an energy transfer at the rate of 1 watt instead of 1 calorie, and k is the conductivity in c.g.s. units.

EXPERIMENTAL

Apparatus.—The method used for carrying out these measurements was the 'double disc' method of Lees as modified by the National Physical Labora-

tory for the experimental investigations on the thermal resistivity of dielectrics.[6] A diagrammatic sketch of the apparatus used has been shown in Figure 1(A).

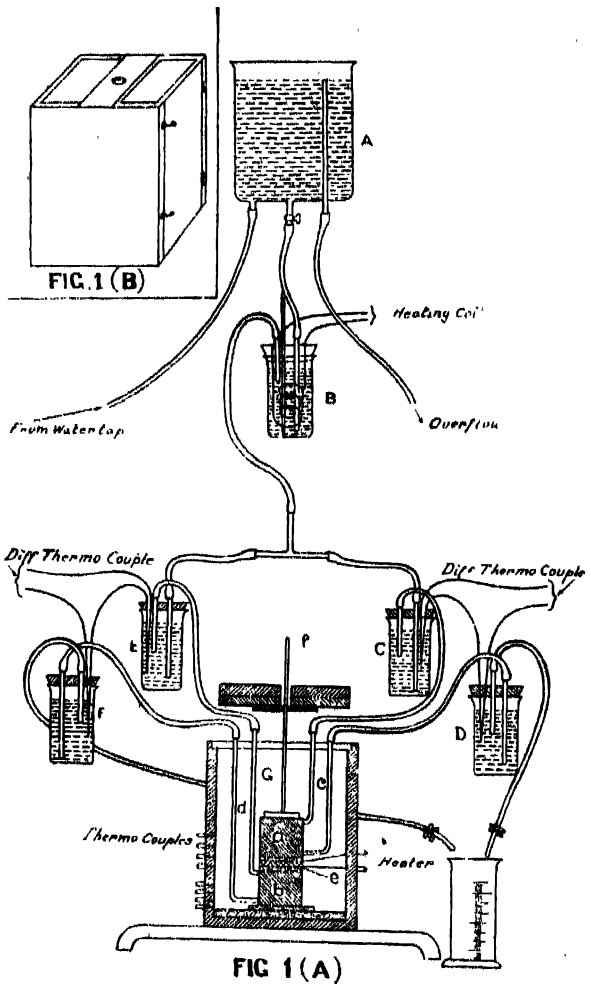

FIG. 1

A was a vessel for supplying water at a constant head and B, a tube which contained a heating coil for regulating the temperature of this water. From B this water was led into two channels by means of a T-piece and each stream passed through another vessel (C and E) just before entering the box G, which contained the main apparatus. On coming out, these streams similarly passed through the vessels D and F before being led out. These vessels C, D, E and F contained differential thermo-couples for measuring very accurately the rise of temperature of the flowing water. The rate of water-flow could be regulated by means of screw-clips.

The main apparatus assembly has been shown inside the box G, where *a* and *b* were two solid copper cylindrical bars kept cold by a steady stream of cold water circulated through two copper spirals (*c*, *d*) which surrounded the outer surface of these two bars and were fixed to them for intimate contact by soldering. *e* was the electrical heater in the form of a disc of the same diameter as that of the copper bars and it consisted of a heating coil of about 8 ohms enclosed between two sheets of mica and encased in a flat copper container. Two exactly similar test samples of each material were employed, one on either surface of the heater, and cold copper bars were placed on the other surface of these specimens as shown in the figure. The surfaces of the copper bars as well as of the heater disc were ground plane in order that there might be good contact between these surfaces and the specimens under test. A copper-constantan thermo-junction was soldered at the centre of the surface of each of these copper bars and connecting leads were taken out through a hole on the sides. Two other thermo-junctions were similarly fixed, one on each surface of the heater. The leads of all these junctions as well as of the heating coil were brought out and fixed with binding terminals on the sides of the wooden box G, the leads of copper and constantan being fixed with terminals of the same material. This box had a hinged door on one side so as to facilitate the assembling of the heater, cold blocks and the specimens. The top of the box was open and a flat steel plate with a central hole, through which an iron rod, *f*, could pass, was fixed on the sides as shown in Fig. 1(B). The rod *f* had a circular steel plate attached to it to carry weights for applying pressure on the samples. The rod rested on an ebonite disc placed on the top of the copper bar in order to isolate it thermally from the main apparatus. The lower copper bar similarly rested on an ebonite and a cork slab. The wooden box G could be filled with cork powder before carrying out an experiment.

The electrical connections for the thermo-couples were made and arranged on a distribution board as described in the E. R. A. Technical Report, Ref. L/T 41, so that either the temperatures of the faces of the test-specimen or their difference could be measured directly on a potentiometer at will. The temperature rise of the inlet and outlet water could also be measured from the same distribution board.

Method of Measurement.—Test samples of a material were first prepared by moulding to a disc of 4 cm. diameter and about 1 mm. thickness. The same thickness of two specimens was obtained by putting into the mould weighed quantity of the material. These samples were then kept in a desiccator for drying.

In assembling the apparatus each time care was taken to see that the axes of copper blocks, heater and test-samples were in line. Though the surfaces of the cold bars and the heater were ground plane as much as possible, it was found that the copper surfaces in contact with the specimens when amalgamated gave a

slightly higher value of conductivity showing thereby a more intimate contact. Subsequently it was found, however, that 'aqua-dag' (colloidal graphite) when diluted to about three times its original volume could be used instead of mercury and the results were practically the same. The advantage of using aqua-dag over mercury was that the latter was found to interfere with any soldering on the copper surfaces, whereas the former had no such disadvantage. For substances which absorb moisture readily, aqua-dag cannot be used. The results of test on the same pair of samples using aqua-dag as well as mercury have been shown in Table I. A small correction for the thermal resistance of aqua-dag or mercury film was determined by blank experiments with thin steel sheets and this was subsequently used in other determinations.

TABLE I

The effect of using mercury or aqua-dag

Pressure = 20 lbs./sq. inch

Sample	With mercury		With aqua-dag	
	Mean Temp. in °C.	Conductivity $k \times 10^5$	Mean Temp. in °C.	Conductivity $k \times 10^5$
Shellac moulding composition No. 91	22·1	25	22.0	25
	33·5	28	33.6	29
	51·0	32	51.4	32
,, ,, ,, ,, 54	23·5	90	23·5	89
	32·7	92	32·9	92
	52·5	93	52·5	94

The effect of applying variable pressure had very little effect as may be seen from the results given in Table II. This may be expected as the materials were all hard enough not to yield under pressure at ordinary temperatures. A dead weight of 40 lbs. equivalent to about 20 lbs. per square inch was then applied constantly on the specimen. The determination was made at different temperatures by regulating the temperature of the inlet water. A set of five copper-constantan thermo-couples used as a differential one and giving 200 microvolts per degree was used for the determination of the temperature-rise of water. Measurements were first made on a Cambridge potentiometer and subsequently on a Tinsley one, both being capable of reading 2μv. The current was supplied from a battery of large-capacity accumulators and the input energy was carefully measured by means of a voltmeter and an ammeter. The rate of water-flow through the copper spirals was regulated in such a way that the temperature-rise of the outlet water could be conveniently measured on the potentiometer. When a steady state was reached, readings were taken on the potentiometer for different points on the distribution board. The output energy could also be determined from the rate of

flow of water and its temperature rise. The input and output energies usually agreed within a few per cent everywhere. It may be pointed out here that the calculation of the output energy from the temperature-rise and the rate of flow of water only served as a check on the measurement of input energy. This did not enter into the actual calculation of conductivity.

TABLE II

The effect of pressure on the samples

Sample	Mean Temp in °C.	Total pressure in lbs.	Conductivity $k \times 10^5$
Kusum shellac	27.3	10	59
		20	60
		40	60
		60	60
	33.0	10	61
		20	61
		40	60
		60	61
Shellac moulding composition No. 72	25.3	10	72
		20	72
		40	72
		60	72
	53.5	10	84
		20	84
		40	82
		60	83

TABLE III

Particulars of shellac moulding compositions used

Shellac moulding composition No.	Resin	Filler	Percentage of		
			Resin	Filler	Dye and mould lubricant
22	Shellac-urea-formaldehyde	Slate dust	30	69	1
23	,,	Fine asbestos	30	69	1
25	,,	Kaolin	30	69	1
54	,,	Fibre asbestos	23	76	1
68	,,	Paddy straw	45	52	3
72	,,	Mica dust	30	69	1
91	,,	Wood flour (1st quality)	48	49	3
179	,,	Wood flour finely ground) (2nd quality)	45	52	3
49 S	Shellac-melamine-formaldehyde	Wood flour (1st quality)	45	52	3

RESULTS

The results of test have been shown in different tables. The particulars of composition of shellac moulding powders which were taken for this work have been shown in Table III. The effect of temperature on the thermal conductivity has been shown in Table IV. The study was confined up to a maximum of 60°C., as it was considered unnecessary to extend it beyond this range for the simple reason that the above temperature might be considered to be the limit for most of the applications to which these materials may be used and as also it was apprehended that the specimens might yield slightly under a heavy load above that temperature. For this reason, thickness measurements were repeated for each specimen after conductivity test in order to see whether any deformation took place at the elevated temperatures. Table V shows the results of thermal conductivity measurements at different temperatures after the specimens were immersed in water for 24 hours. This gives an idea of the effect of water on thermal conductivity of shellac-moulded articles.

Accuracy.—The power input could be measured to an accuracy of 0.5% and the measurements of thickness which were done with a micrometer screw gauge were correct within 2%. Special copper and constantan wires for thermo-couple purposes were used and the calibration done up to about 100°C. was found to be in good agreement with the data given in the International Critical Tables. Temperature measurements might, therefore, be thought to be accurate to within 2% for worst cases and within 1% for most cases. The overall accuracy, therefore, may be considered to be within 5%.

DISCUSSION

The value obtained by Lees for shellac at a temperature of 35°C. is practically the same as found here for Kusum shellac. The slight discrepancy is well within experimental error or even this may be attributed to the difference in the samples. The specimen of shellac used in these experiments was a genuine Kusum one manufactured at the experimental factory of this Institute but nothing unfortunately is known about the purity of the sample of shellac used by Lees. The agreement of the two values, however, is quite good. The value for shellac given in this paper confirms the figure obtained in a very recent work carried out in America.[7] It may be seen from Tables IV and V that no change in the thermal conductivity of Kusum shellac takes place even after immersion in water for 24 hours. Therefore, it may be assumed that atmospheric humidity will have practically no effect on the thermal conductivity of shellac. Commercial dewaxed lac, however, shows slight increase in conductivity after water immersion. On the other hand, the conductivity of pure lac resin increases to a greater extent on immersion in water. It is difficult to explain this increase in conductivity, since hard resin is not known to absorb more

TABLE IV

Thermal conductivity of desiccated materials at different temperatures

Materials	Thickness in cm.	Temp. of hot face in °C.	Temp. of cold face in °C.	Mean Temp in °C.	Conductivity $k \times 10^6$	Resistivity K
Knsum shellac	0.176	41.0	25 0	33.0	61	394
		28.8	25.9	27.3	60	400
Dewaxed lac (lemon)	0.170	43.0	26.9	35.2	56	420
		32.8	26.6	29.7	56	429
		29.3	26 5	27.9	56	429
Pure lac resin (ether extracted)	0.121	44.1	30.3	37.2	49	490
		32.7	27.5	30.1	47	511
		30.4	27.7	29.0	47	511
Shellac-urea-formaldehyde resin	0.155	41 5	26.7	34.1	57	421
		32.6	27.1	29.9	56	429
		29.6	26 8	28.2	56	429
Shellac-melamine-formaldehyde resin	0.128	40.7	25.9	33.3	48	500
		31.5	25 7	28.6	46	522
		28.8	26.2	27.5	45	533
Shellac moulding composition No. 22	0.164	33.0	22.0	27.5	83	289
		45.5	40.3	42.9	104	231
		58.5	50.2	54.4	106	226
		34.7	31.7	33.2	101	237
		33.3	22.3	27.8	83	289
Shellac moulding composition No. 23	0.082	28.0	24.0	26.0	96	250
		28.7	25.0	27.4	94	255
		30.0	25.3	27.7	94	255
		52.4	49.0	50 7	101	237
Shellac moulding composition No. 25	0.090	29.3	21 9	25 6	75	320
		36.0	33.8	34 9	89	269
		59.6	53.6	56.6	92	261
Shellac moulding composition No. 54	0.086	26.3	20.7	23.5	89	269
		33.8	32.0	32.9	92	261
		55.1	50 0	52.5	94	255
Shellac moulding composition No. 68	0.210	39.2	21.2	30.2	58	414
		41.9	23.1	32.5	59	407
		47.6	36.8	42.2	61	394
		59.3	42.8	51.1	64	375
Shellac moulding composition No. 72	0.093	28.3	22.3	25.3	72	333
		56.2	50.8	53.5	84	285
Shellac moulding composition No 91	0 042	23.7	20.3	22 0	25	960
		35.1	32.1	33.6	29	827
		54.4	48.5	51.4	32	750
Shellac moulding composition No. 179	0.055	26.7	20.7	23.7	47	511
		33.4	31.3	32.4	48	500
		53.5	47.7	50 6	49	489
Shellac moulding composition No. 498	0.065	26.0	20 5	23.3	56	429
		31 3	29.2	30.3	56	429
		52.3	47.4	49.8	58	414

TABLE V

Thermal conductivity of materials at different temperatures after immersion in water for 24 hours

Materials	Thickness in cm.	Temp. of hot face in °C.	Temp. of cold face in °C.	Mean Temp. in °C.	Conductivity $k \times 10^5$	Resistivity K
Kusum shellac	0.176	43.5	27.9	35.8	61	394
		28 6	25.6	27.1	61	394
Dewaxed lac (lemon)	0 170	44.3	27.9	36.1	58	414
		28.8	26.0	27.4	57	421
Pure lac resin (ether extracted)	0 121	38.0	27.0	32.5	60	400
		30.6	26.7	28 6	62	387
Shellac-urea-formaldehyde resin	0.155	41.8	28.9	35.0	60	400
		33.8	28.8	31.3	62	387
		31.1	28.8	29.9	60	400
Shellac-melamine-formaldehyde resin	0.128	41 8	29.1	35.5	55	438
		34.0	29.0	31.5	52	461
		31.25	29.0	30.2	50	480
Shellac moulding composition No. 22	0.164	28.5	22.4	24.2	126	190
		47.1	41.4	44.2	135	178
Shellac moulding composition No. 23	0.082	44.8	41.7	43.3	123	195
		22.9	19.3	21.1	106	226
Shellac moulding composition No. 25	0.090	24 2	20.3	22 2	116	207
		32.9	31.6	32.3	126	190
		52 6	48.3	50.5	124	193
Shellac moulding composition No. 54	0.086	24.4	20.9	22.6	168	143
		31.9	30.9	31.4	171	140
		51 3	48.5	49.9	168	143
Shellac moulding composition No. 68	0.210	35.3	20.5	27.9	67	358
		58.5	44.6	51.5	70	343
		41.0	34.7	37.8	68	353
Shellac moulding composition No. 72	0 093	24.4	20 3	22.3	104	231
		32.5	30.9	31.7	124	193
		49.8	45.9	47.8	111	216
Shellac moulding composition No. 91	0.042	25.0	19.3	22.2	41	585
		28.6	26.5	27.6	41	585
		54.1	48.5	51.3	41	585
Shellac moulding composition No. 179	0.055	23.0	20.0	21.5	63	380
		32.6	30.8	31.7	61	394
		50.1	45.8	48.0	58	414
Shellac moulding composition No. 49 S	0.065	23.0	18.3	20.7	84	285
		30.0	28.1	29.0	81	296
		54.4	49.6	52.0	82	292

moisture than shellac. In the form of films rather this resin is said to be more water-resistant than shellac in the sense that it is 'nonblushing' whereas shellac films 'blush' in contact with water. Properties of resins in the form of moulded disc or cast otherwise by melting, however, differ fundamentally from those of their varnish films obtained from solutions. Even the properties of films in different solvents vary widely. The moulded disc of Kusum or dewaxed lac (thickness about 1 mm.) was found, for example, not to blush even after 96 hours' water immersion, although their films made from alcoholic solution are known to blush after a few hours' immersion in water. The water absorption data of pure lac resin-moulded disc did not show such a value that so much difference in conductivity after water immersion might be accounted for. The explanation may be that there were very fine cracks in the desiccated pure lac specimens and the apparent low value of conductivity owing to their presence was made good by the absorbed water, however small. Aldis[8] has shown how cracks develop in the desiccated lac samples. It might be said in this connection that water, although a bad thermal conductor itself, may be considered to be a better conductor when compared with substances like lac, ebonite, etc., and the absorption of water, therefore, resulted in an increase in their conductivity.

The shellac-urea-formaldehyde and shellac-melamine-formaldehyde resins (*i.e.*, without any filler) were found to be affected by water but slightly, but most of the shellac moulding compositions were affected by it to a greater extent. Undoubtedly the fillers were responsible for this. This may be seen from the values for compositions Nos. 23 and 54. In both these powders asbestos was used as filler but the latter contained a greater percentage of it and the change of its conductivity was also higher after water absorption. The mineral fillers, in general, gave greater thermal conductivity than organic fillers. Wood flour when used as filler decreased the conductivity of the shellac-urea-formaldehyde resins. But when used with shellac-melamine-formaldehyde resin it showed a slight increase in conductivity. This may be explained on the ground that other ingredients such as dyes, mould-lubricants, etc., are also present in moulding powders and that they also affect the heat conductivity of such compositions to a small extent. Moreover, wood flour itself has different grades and their conductivity was found to be different. This may be seen from the values of composition Nos. 91 and 179.

Comparing the values of other insulating materials it may be seen that thermal conductivity of shellac mouldings is of the same order of magnitude as those of pressboard, varnished cloth, treated silk, ebonite, phenol-formaldehyde resin compositions, and paraffin. As mica has a slightly higher value of thermal conductivity, the shellac moulding composition containing mica dust has yielded a comparatively high value. It was expected, therefore, that compositions containing mica dust as filler would have better thermal as well as dielectric

properties. This expectation has subsequently been found to be true." But unfortunately the mechanical strength of such a composition is inferior.

The variation of thermal conductivity with the temperature of materials tested before and after immersion in water shows a marked difference. In most cases the temperature had very little effect on conductivity after immersion in water. The explanation may be that at higher temperatures moisture is eliminated from the specimen which has absorbed water and the consequent fall in the value of its conductivity annuls the increase due to the temperature rise. This view is substantiated from the figures of composition No. 23 in Table V, where measurement at the higher temperature was done first. Here the increase in conductivity at the higher temperature has been obtained. The results of test obtained after the samples were immersed in water and recorded in Table V are, therefore, not so accurate. They indicate, however, how these composition are affected by water.

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